line frequency. The source of these harmonics was always line-synchronous switching devices usually operated by customers of the utility. These harmonics changed in amplitude as customer loads were turned on and off or as the loads were adjusted. The harmonics varied in amplitude with location along the line. A number of sources were identified with harmonics that were far too high in amplitude to allow a DLC terminal located at or near the source to operate successfully. For a DLC terminal at or near such sources to operate successfully operate requires adding devices on the customer equipment to suppress harmonics or some form of isolation between the customer's equipment and the distribution line. These underirable sources of harmonics at DLC frequencies came from from homes, small business, shopping centers, large business, and hospitals--and virtually all types of customers.

The control and suppression of harmonics generated by customers will be necessary on a wide scale to implement DLC systems completely successfully. Otherwise, customers will continue to install and operate harmonic producing loads that will prevent DLC equipment from operating successfully at the customer's location and in the immediate vicinity of the customer's location. Reducing the general level of harmonics on distribution lines at DLC frequencies will result in a significant expansion in the distances that useful signals can be propagated along DLC lines. In addition, fewer remote terminals will operate on marginal signal-to-noise ratios.

The data show that ongoing efforts to control and mitigate harmonics and noise on distribution lines are needed. Since all utilities at which measurements were made had similar harmonic conditions, the problem is believed to be a nationwide in extent. EPRI and the utilities need to develop and implement additional harmonic and noise suppression efforts. This will be a difficult program to implement since nonutility entities are responsible for the generation of most excessive harmonics and noise.

Instrumentation to make the necessary harmonic measurements to implement control measures is not generally available at utilities. A few utilities have some of the necessary instrumentation, and others are now beginning to take steps to obtain such instrumentation. Instrumentation in Configuration C described in Section 3, supplemented with appropriate probes and sensors, is sufficient to measure and define many cases of excessive harmonics at DLC frequencies. More complex instrumentation will be required to fully investigate all harmonic and noise conditions, especially the time-varying (nonstationary) and transient cases.

6.3 OTHER SIGNALS AT DLC FREQUENCIES

The presence of a modest number of non-DLC signals on distribution lines must be considered in any program to implement DLC systems orderly and successfully on a large scale. These signals have either been unknown to the utilities owning the affected distribution lines, or they have been tolerated as a harmless auxiliary use of the lines by customers. As DLC systems become more generally used, these signals will become serious sources of interference to them. The utilities must take steps to control and manage these signals.

The signals are on distribution lines because the cost of transmission over utility lines is less than that of alternate means of transmission (i.e. telephone lines and radio). No other wire-line carrier provides the totally free communication transmission service that the electric utilities provide. The practice of using utility distribution lines has quietly, informally, and unofficially grown into a sizeable means of communication. It will continue to grow because the cost of data transmission are so favorable to the operators of such systems.

In most cases the utilities are not even aware that customers are using their lines to transmit communication signals, and most utilities do not own the equipment needed to detect the presence of the signals on their lines. The operators of such communication systems do not coordinate their use of distribution lines with the utilities owning the lines. An informal situtation has evolved in which the users of such systems assume that the utilities are not in the communication business and, hence, have no interest in communication signals on distribution lines. This uncontrolled use of utility distribution lines for communication will become a prime issue in the next few years as DLC systems expand and as cases of conflicts for frequency space on the lines become evident.

The utilities clearly need to set nationwide policies concerning the use of their lines for the transmission of communication signals. In setting these policies, the following issues must be considered:

(1) Establish guidelines for the use of distribution lines for communications by customers or to prohibit the practice.

(2) Set aside a few frequencies with specified channel width for customer communication, and let the customers coordinate their own use of these channels.

(3) In the future, establish the cost of administering the use of distribution lines for customer-operated communication, because (1) conflicts for frequencies will arise, (2) faulty equipment will occassionally cause spurious signals at other frequencies, (3) harmonics must be controlled, (4) records of users must be kept so that complaints of interference to utility DLC systems can be investigated, and (4) other related matters. The utilities need to carefully examine the cost of these items and take steps to minimize future costs.

6.4 GAP NOISE

Gap noise was present on virtually all distribution lines that were examined during the project. The spectral and temporal properties of gap noise were so consistent and repeatable that it was very easy to identify the noise. Even though gap noise was often erratic and intermittent, the unique temporal properties provided a distinctive signature. In all cases that were investigated in detail, the sources of gap noise were metal hardware on poles for the distribution lines. Nelson [7] has described a large number of hardware configurations that cause gap noise, and his Interferrence Handbook is a practical and useful manual for those interested in the general topic of RFI complaints including mechasims that produce power-line noise.

Gap noise is a major source of interference to a number of radio services with receiving antennas that are located near distribution lines. These include HF radio reception, amateur radio, citizens band radio, foreign broadcast reception, VHF mobile radio, VHF television, FM radio, and other users of the spectrum from about 30 kHz to above 500 MHz. Gap noise causes a large number of complaints about RFI; probably more complaints than all other sources of noise.

Many of the utilities have a small RFI group that can respond to noise complaints. Some of these groups are becoming experienced at locating and eliminating sources of gap noise. While most utilities will respond to complaints about RFI, none were found that had an operating policy directed toward the total elimination of gap noise.

Gap noise produced no significance intereference at DLC frequencies. Gap source energy was so low at frequencies below about 30 to 50 kHz that even nearby gap sources did not interfere with DLC communication systems. Figure 6-1 shows gap noise and noise from switching devices at a DLC receiver location. Strong gap noise was the dominant noise in the view from the upper frequency limit of the data of 100 kHz down to 30 kHz. From 30 kHz downward in frequency, gap noise decreased in amplitude while synchronous impulsive noise peaked in amplitude at 30 kHz. Below about 30 kHz, synchronous impulsive noise was the dominate form of noise.

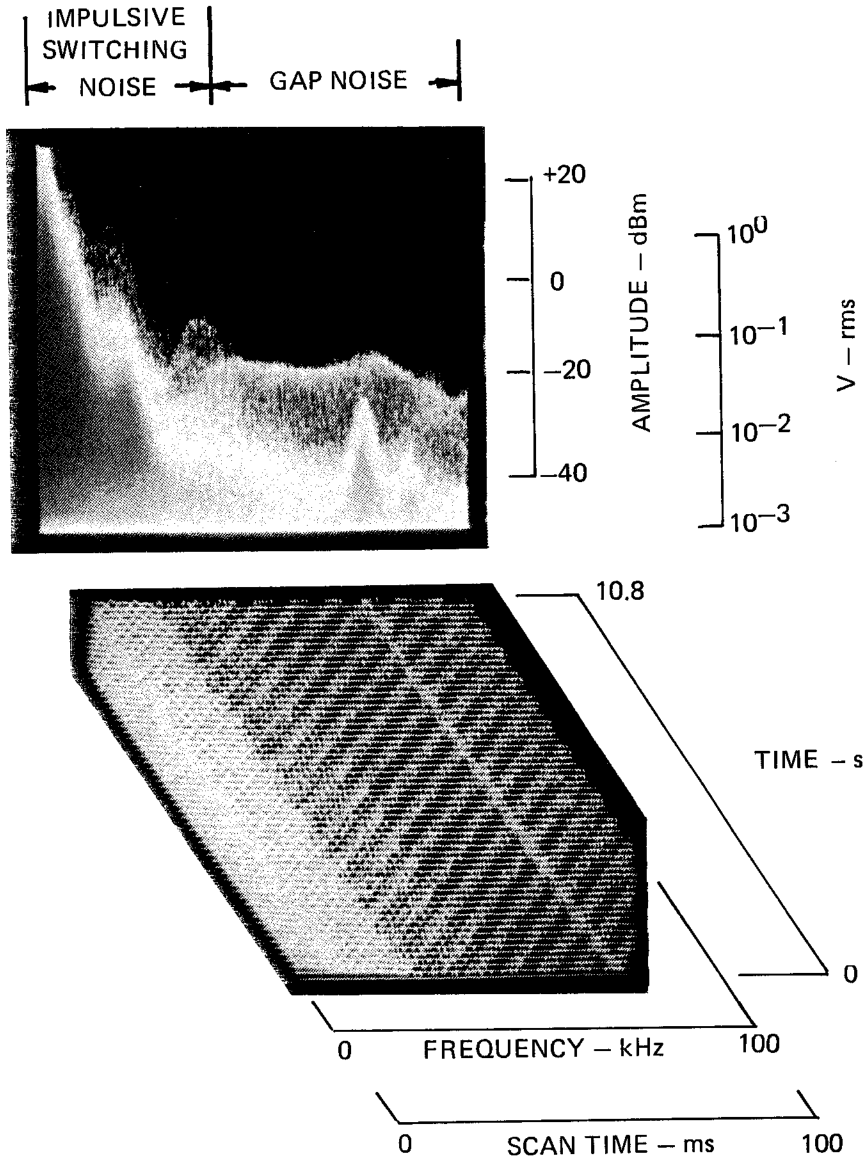

Figure 6-1. Dominant Type of Noise vs. Frequency

Section 7

MITIGATION OF HARMONICS, SIGNALS, AND NOISE

7.1 GENERAL COMMENTS

Devices operated by utility customers have been identified to be the dominant sources of harmonics and noise that affect the performance of DLC communication systems. These devices are usually line-synchronuous-switching equipment that are used to control the operation or performance of electrical loads. The actual devices include SCR controllers, battery chargers, equipment containing rectifiers, and other related electrical equipment.

Other common types of radio noise associated with distribution lines, such as gap noise, are unlikely to interfere with the operation of DLC systems. Gap noise, however, may be a primary source of interference to other communication systems. Only one suspected case of distribution-line equipment that interfered with the operation of a remote DLC receiver (see Section 5.3.1) was found during the entire investigation. This was a case of DLC signal intermodulation with the 60-Hz line frequency. The actual location of the nonlinear device producing the intermodulation was not determined.

Identifying the primary sources of harmonics and noise that limit the performance of DLC system receivers has now focused attention on ways to mitigate the effects of these sources. Although an extensive investigation of mitigation techniques was not completed, the preliminary work provides information useful for establishing guidelines for future mitigation work. The report does not provide complete solutions for the very complex problems that are associated with the mitigation of harmonics, signals, and noise that affect the performance of DLC systems.

Examination of mitigation problems suggests that they can be divided into five catagories:

(A) Source-device mitigation
(B) Source-location mitigation
(C) Area mitigation
(D) Terminal mitigation
(E) Other-signal mitigation

In considering these catagories, it is recognized that the utilities are often limited in their ability to (1) identify the sources of harmonics, signals, and noise that limit DLC system performance and (2) impose mitigation requirements on customers. The first item requires that the utilities obtain the equipment necessary to identify, measure, and locate sources of harmonics, signals, and noise in sufficient detail to trouble- shoot and cure DLC performance problems. This also requires that the utilities acquire the expertise to use the equipment successfully by training of existing personnel or by hiring additional suitably trained personnel. The second item, will require that the utilities develop long-term policies regarding the electrical pollution of distribution lines and of distribution-line secondaries by customers.

Quick and easy mitigation solutions may be possible for specific cases, but the widespread implementation of the mitigation techniques necessary for nationwide use of DCL may require extensive efforts.

7.2 SOURCE-DEVICE MITIGATION

The most effective method of mitigating harmonics and noise that affect DLC system performance is at the source. A number of commercial devices are available to filter and isolate electrical loads from their sources. These devices need to be carefully examined to deterimine their effectiviness for isolating sources from the power distribution system.

A simple and direct approach would be to purchase filters, isolation transformers, or power purifiers for the offending devices. These solutions may not be universally satisfactory because of a number of factors. The low-pass frequency cutoff for most standard power-line filters for use on customer operated equipment is about 15 kHz; a value too high to eliminate the spectral components of harmonics and noise that interfere with DLC systems operating in the frequency range of 1 to 15 kHz. The impedance levels of harmonic and noise components are frequently too low for the effective use of standard filter designs. Also, harmonics and noise at DLC frequencies that are generated by customer loads flow in grounds, neutrals, and green (saftey) wires; often at levels that are equal to the levels in hot wires. These secondary paths for the conduction of harmonic and noise potentials and currents must be considered in any successful mitigation program.

The belief is widespread that the use of good earth grounds can suppress interference and noise. This is not true. Good grounds (i.e. low-resistance grounds) often increase the level of ground currents and thereby enhance interference and noise problems rather than suppress them. The best designed equipment inject very low harmonic and noise currents into their power and ground conductors and use grounds strictly for safety.

The ability of several types of commercial isolation transformers and power purifiers to isolate harmonic and noise producing sources found in residences from the residence wiring was briefly examined in Supplemental Task 6 (Section 4.12). The results were not encouraging in that some units actually increased ambient harmonic levels, and no unit eliminated all harmonics and noise at the frequencies of primary interest. These units were designed for industrial applications rather than for home applications, and they may perform better in their intended use.

Voltage and current harmonic suppression can be considered as separate, but related, mitigation problems. Standard filter designs can be effective in suppressing voltage harmonics and noise because of the high impedance levels involved. Current harmonics can be suppressed by ferrite absorbers; however, suitable absorbers are not available as standard products. The instrumentation van used for measurements on this project uses ferrite absorbers to isolate current harmonics and noise generated by the diesel generator from the instrumentation. A second set of absorbers is used to isolate harmonics and noise generated by the van's instrumentation from wires and cables outside the instrumentation van. These units were designed and constructed to remedy a specific problem. Additional special purpose units are now being designed and built for other specific applications including isolating an RF-stabilized arc welder from its power source and isolating equipment in shielded rooms. The considerations involved in the design of these special purpose devices, however, has not yet evolved into a convenient handbook of design procedure.

In suppressing voltage and current harmonics and noise, the filter elements and the ferrite absorbers must be capable of dissipating the harmonic power generated by the source without introducing nonlinearities (and the accompanying harmonic and intermodulation generation processes). In addition, the elimination of low-frequency harmonics can sometimes alter the voltage and current waveshapes of power delivered to a customer appliance or load, when those waveshapes are already distorted.

7.3 SOURCE-LOCATION MITIGATION

Some utility customers operate resistive loads that produce classic sine-wave current waveforms. These customers will not generate serious harmonic or noise interference to DLC systems, and source mitigation isolation need not be considered for such customers.

Other customers use large nonlinear loads that severely distort the current waveform of electrical power provided by the utility. This distortion generates severe current harmonics on all conductors involved in providing power to the customer including ground and neutral conductors. The resistive and reactive impedances associated with these conductors and with grounds generate harmonic potentials on the conductors.

The possibility of suppressing harmoics and noise generated by customers at DLC frequencies at the entrance of power into the customer locations needs careful consideration. Remote DLC terminals are usually placed at the watthour meter of a customer. A logical location for a harmonic and noise mitigation device is between the DLC unit and the meter, or between the meter and the customer location being metered. In theory, this would prevent customer generated harmonics and noise from entering the power distribution system. However, a few practical problems prevent the immediate implementation of such a device. Because harmonic and noise voltages and currents flow on all conductors entering a customer's location, including grounds and saftey wires, all conductors entering a customers facility must be treated. The implications of filters and isolators on ground, neutral, and saftey conductors need considerable study and may require revising electrical wiring practices (and perhaps the clarifiction of portions of electrical codes).

Harmonic and noise currents should be returned to their source by the shortest possible path that does not include a path the power source. If these currents and potentials are present on ground, neutral, and saftey conductors, the path for their return to a source can be complex and usually involves paths through the power system. These uncontrolled paths often generate interesting interference problems for computing and communication equipment.

It is common practice in troublesome cases to return common-mode harmonic and noise currents to their source through grounds. The general rule is "put in a good earth ground" with the implication that the earth absorbs harmonic and noise ground currents. Good earth grounds merely provide a complicated and difficult to trace path for the return of harmonic and noise currents to their source. Grounds, improperly used, often generate more interference control problems than they eliminate.

An obvious solution to the generation of harmonics and noise at a customers facility would be to place rigid specifications on all source equipment that would eliminate harmonic and noise currents and potentials on all ground and safety conductors. This would require that the manufacturers of equipment return all undesired potentials and currents to their source within each piece of equipment. This solution is presently being considered for some critical military computer and communication equipment in which ground currents are highly undesirable. The extension of this concept to commercial equipment requires forming and implementing of new standards and policies.

Two methods of harmonic and noise control at the source need to be further examined:

(1) Conduct a detailed examination of harmonic and noise control by improving the design of customer equipment. This will require a long-term approach to the problem since since waveform control or harmonic content control of load current is not presently a factor used in evaluating consumer equipment.

(2) Investigate and conduct field experiments on filter and absorber devices that can be added to a customers meter to isolate customer generated harmonics and noise from the power system.

7.4 AREA MITIGATION

In cases in which several customers generate serious harmonic and noise levels, it may be more expedient to isolate these customers from the power distribution system as a group rather than individually. This can be done by adding capacitors or filters to a distribution line at appropiate locations. While capacitors provide a conducting path to suppress harmonic potentials, they also will suppress DLC signals (unless equipped with inductors to isolate the DLC frequency). In addition, care must be taken to avoid harmonic resonances on a distribution line that might be caused by adding capacitors. It is not clear whether capacitors can be used to suppress harmonic and noise currents flowing in ground of neutral conductors and in shield wires.

Filters can be added to distribution lines to control noise and harmonics. Such filters are not presently available as standard items. In principle, a harmonic-and-noise-suppression filter can be designed and built. But, considerable engineering work is required to construct and field test sample units. In addition, consideration must be given to the implications of adding filters to ground, neutral, and shield conductors to suppress the flow of harmonic and noise currents in these paths.

7.5 TERMINAL MITIGATION

Many DLC terminals will be located in substations and other facilities that contain extensive electrical equipment. Controlling harmonics and noise at DLC frequencies in substations and other facilities sufficiently to permit operating DLC receivers will require considering low-frequency signal and noise coupling mechanisms. Harmonics and noise from outside sources must be suppressed before they enter the DLC receiver, and harmonics and noise from other collocated equipment must be prevented from interfering with the operation of a DLC receiver. In severe cases, metallic buildings of shielded rooms can be provided to contain a source of harmonics or noise or to protect a DLC receiver from nearby sources. Using metal buildings and shielded rooms at DLC frequencies, however, requires considering a number of technical factors, discussed below.

Shielded enclosures provide considerable isolation from ambient electric fields; typically 60 to 80 dB at all frequencies. Shielding from low-frequency magnetic fields, however, can be very low. A typical high-quality shielded enclosure will provide only about 10 dB of isolation for inductive-zone magnetic fields at a frequency of 1 kHz. The isolation provided by a room constructed with walls of copper screen to low-frequency magnetic fields will be even lower; typically less than 3 dB at 1 kHz. Ambient magnetic fields from nearby sources penetrate shielded enclosures with relative ease and can induce common-mode currents in internal conductors and cables at levels of concern for the operation of a DLC receiver. At frequencies above about 20 kHz, the wall isolation provided by most shielded enclosures to magnetic fields will increase to useful values. But, frequencies at which increased attenuation occurs is above the operating frequencies of DLC systems.

Conductors that penetrate the walls of a metal building or a shielded enclosure also provide paths for harmonics and noise to enter or leave the enclosure. Any conductor penetrating a room, whether the room is shielded enclosure or not, can conduct undesired harmonics and noise into, or out of, the room. This is especially true for power wires, neutral wires, grounds, and green (safety) wires.

Two types of conducting paths must be considered for the entry or exit of harmonics and noise into a shielded enclosure or any room containing sensitive equipment:

(1) Standard shielded-room power-line filters have a low-pass cutoff frequency of about 15 kHz. This is above the upper limit of proposed DLC operating frequencies, and filters are not effective for suppressing harmonics and noise at DLC frequencies.

(2) Neutral wires, ground wires, and safety wires often penetrate the walls of shielded facilities without filters, and hence, can conduct harmonic and noise at even higher frequencies into or out of such rooms without loss or attenuation.

Figures 7-1 and 7-2 provide typical examples of conducting paths into or out of metal buildings or shielded enclosures. Figure 7-1 shows a diagram of a typical installation of a power-line filter for a building wall or a shielded enclosure. The filter ground is usually connected to the outside wall of the room. For this configuration, harmonic and noise current generated inside the room, at all frequencies higher than the filter cutoff frequency, are conducted through the wall and and onto the outer wall of the room. Harmonic and noise voltage and current spectral components below the filter cutoff frequency (about 15 kHz) will flow along the conductor into or out of the room without attenuation. Thus, standard power-line filters do not provide isolation at DLC frequencies.

Figure 7-1 shows how most grounds penetrate the walls of metallic buildings and shielded enclosures. Green (safety) wires and power neutral wires also penetrate the wall in a similar manner. Any harmonic or noise ground current generated by equipment located inside the enclosure will be conducted outside the enclosure. Harmonics and noise generated by other equipment connected to the same ground can be conducted into the enclosure if this is the path of lowest impedance for the current to flow back to its source. In addition, ground potentials developed across the ground resistance can result in ground currents flowing on the ground wire and into the enclosure.

The above discussion describes some of the problems facing an engineer trying to isolate a communication or computer system from nearby sources of electromagnetic fields and from the conduction of harmonics and noise being conducted into or out of a shielded

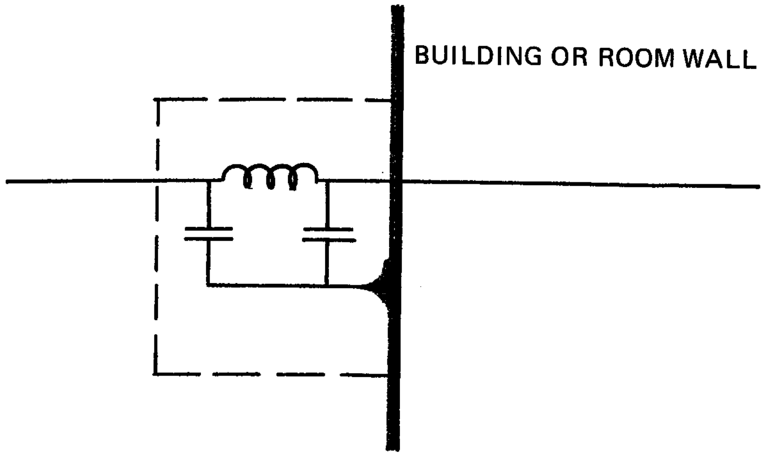

Figure 7-1. Typical Power-Filter Connection

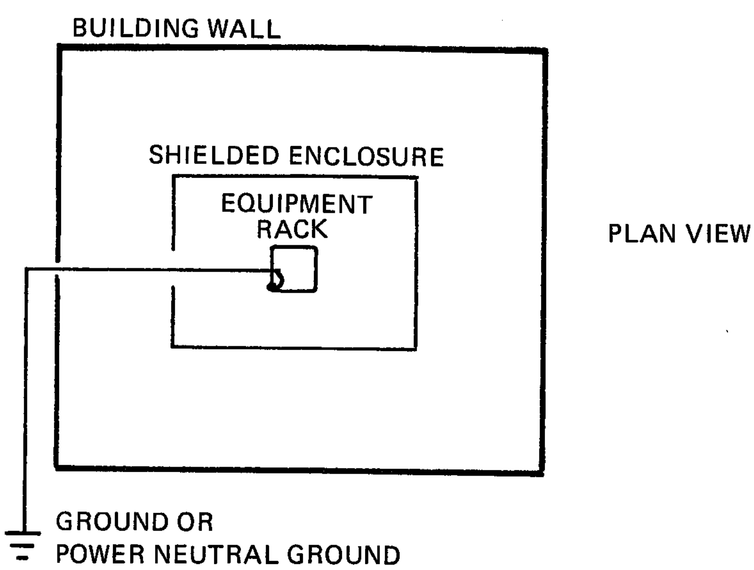

Figure 7-2. Typical Ground Installation

enclosure. Solutions to these problems are possible, and a brief discussion of some of the concepts involved in the solutions follows.

Figure 7-3 shows the optimum method of controlling currents that flow on ground leads. Starting with a building constructed with metal walls (a conventional Butler building with walls, roof, and, floor properly bonded is an excellent outer shell), the external earth ground is connected to the outer wall of the building. The interior surface of the building wall is bonded to the exterior surface of the wall of an internal metal enclosure. The inner wall of the enclosure is bonded to the outer surface of an equipment enclosure, and the inner wall surface of the equipment cabinet is connected to the outer surface of equipment mounted in the cabinet. This series of ground connections keeps harmonic and noise currents on the wall surface nearest their source and returns ground currents to their source with minimum coupling to the next region.

All penetrations of metal walls must pass through filters and isolators whose bandpass is limited to the bandwidths of those signals necessary for the proper operation of internal or external equipment. These filters and isolators must be constructed so that they return undesired harmonics, signals, and noise to the proper surface. Figure 7-4 shows the basic configuration of such a filter or isolator.

An extremely useful feature of a facility designed in accordance with the concepts shown in Figures 7-3 and 7-4 is that practical test points are provided for measuring the temporal and spectral properties of all signals entering and leaving the various barrier walls. This includes measuring harmonics and noise flowing on grounds, safety wires, cable shields, and power wires. Harmonic and noise potentials can be measured between any two adjacent wall surfaces with a wideband voltage probe, and currents can be measured on any interconnecting ground bus or other conductor with a wideband current clamp. Also, the temporal and spectral properities of signals on any penetrating wire or cable can be measured with an appropiately impedance matched voltage or current probe. This easy access to test points provides a definitive means of evaluating and analyzing the affect of ground potentials and currents on the operation of computer and communication equipment.

Implementating of this method of controlling conducted signals and radiated fields is feasible in theory, but it is not consistent with many common practices in electrical construction. For example, conductors from earth grounds frequently penetrate a metal wall (sometimes several metal walls) to connect directly to equipment--a poor practice from the standpoint of electrical interference. Most power-line filters are designed to return their ground connection to only one surface of a wall--also a poor practice from the standpoint of electrical interference. Green (safety) wires are usually routed from internal equipment directly to externally located neutral grounds; a poor practice from the standpoint of electrical interference and a questionable safety procedure since it provides a direct path for conducting high-transient potentials caused by power-system failures (and by lightning) to equipment areas.

The method of controlling conducted potentials and currents

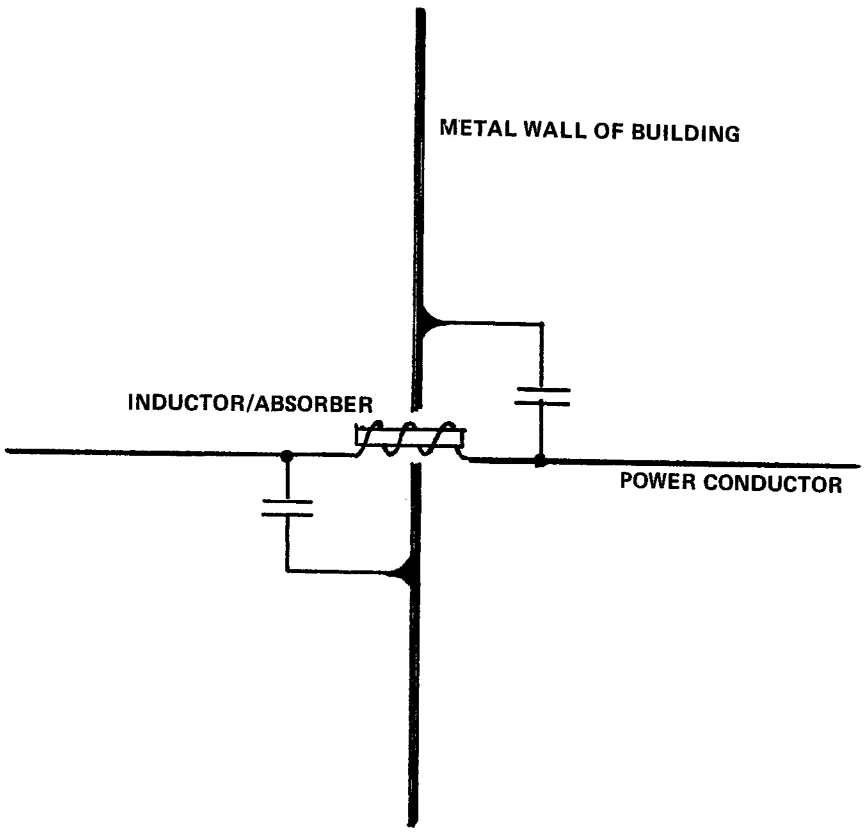

Figure 7-3. Recommended Filter Installation

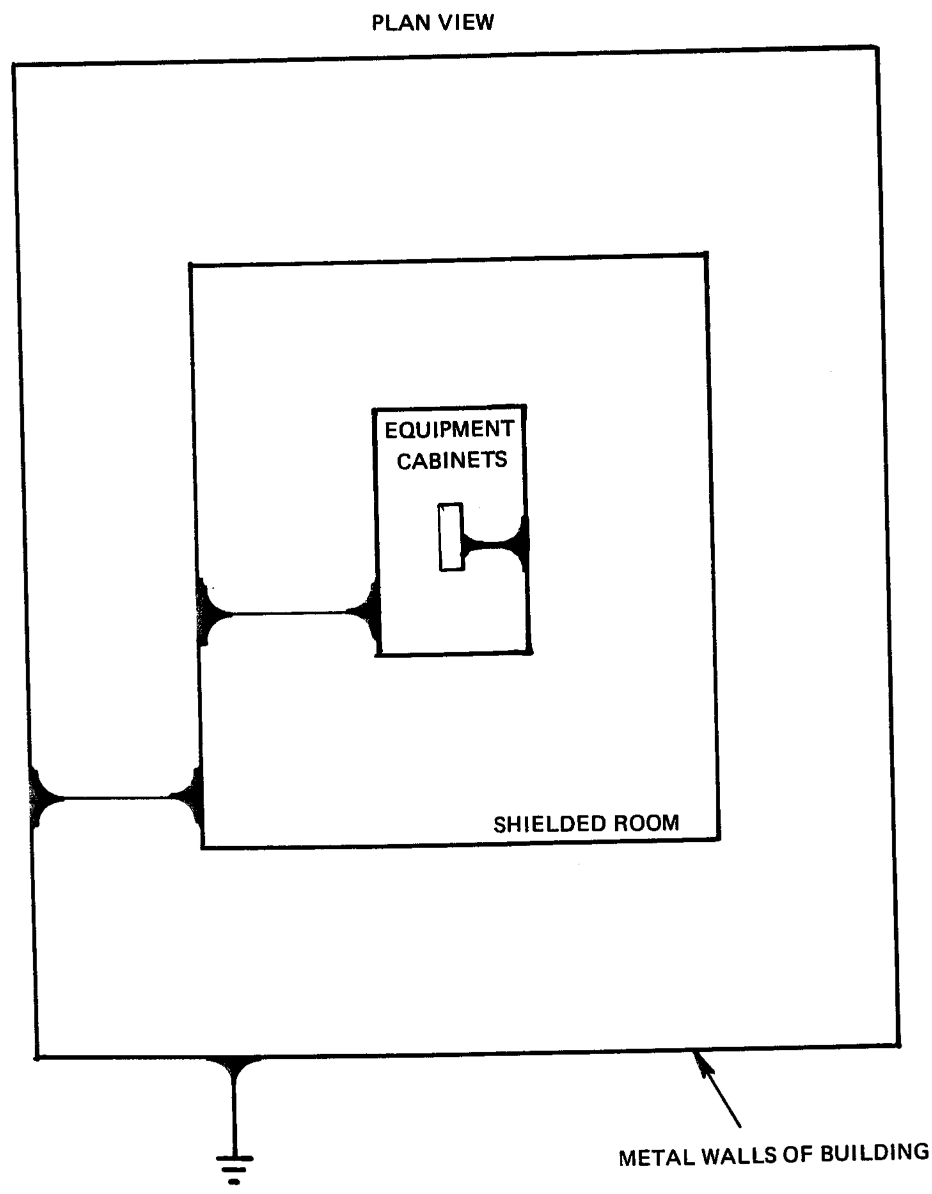

Figure 7-4. Recommended Ground Connections

suggested above must not be interperted as an attempt to modify the control of 60-Hz currents and potentials in neutral conductors caused by unbalanced three-phase loads in utility transmission and distribution systems or in customer facilities that have large three-phase loads. The utilities cannot be expected to maintain a perfect balance in three-phase power systems, and their methods of handling the unbalanced currents are not affected by the above discussion. The above discussion applies only the isolation of communication, computer, and similar facilities from sources of harmonics and noise.

7.6 OTHER-SIGNAL MITIGATION

Sections 5.3.2 and 6.3 describe other signals that were found on distribution lines. These signals are at frequencies useful for DLC systems. The signals were generated by utility customers using utility distribution lines and secondaries to conduct communication signals from one location to another location.

Although the number of these nonDLC signals at most utilities was modest and no case of interference to DLC systems was observed, sooner or later, these signals will interfere with a DLC system. As the number of nonDLC systems increase and the number of DLC systems increase (along with their coverage areas), the potential for serious interference will increase. Eventually, the interference will become a major factor limiting DLC system performance. The uncontrolled and uncoordinated use of utility distribution lines for communication systems by customers must not be allowed to reach an unmanagable state. The utilities must set policies for the use of their distribution lines for communications. Several options are available:

(A) Prohibit the use of distribution lines for customer communication purposes.

(B) Set aside a few frequencies and specified bandwidths for customer-operated communication systems and donate this frequency space for customer use and good will.

(C) Require that customers limit the coverage of their systems to well-defined distances (This means placing filters on utility lines to limit signal propagation distances).

(D) Establish a new communication service and sell the service to customers.

(E) Set rates and specifications for customer use of distribution lines for communications purposes similar to obtaining a leased line from the telephone company

(F) Ignore the situtation and eventually pay a high managment, legal, and technical price for interference control.

Each of the options listed above, or combinations of these options, provide an uncomfortable and undesirable set of problems for the electric power utilities. Yet, the issues stated must be faced for the successful nationwide implementation of DLC systems.

This project provided the data that identified the nonDLC-signal problem but did not fully explore all the implications and issues involved in solutions to the problem. Additional work by the utilities and by utility organizations could establish a nationwide policy on the use of distribution lines for customer communication.

Section 8

CONCLUSIONS

The work accomplished under the effort described in this report produced a number of findings and conclusions regarding harmonics, conducted electrical noise, and near-zone radiated noise that are associated with distribution lines. These conclusions are summarized in the following statements.

* Harmonics, conducted electrical noise, and near-zone radiated noise effects that would impact on the operation of DLC systems were remarkably similar on all distribution lines at all utilities visited. No significant difference in the amplitude of harmonics and noise could be attributed to location in the country, smooth terrian, rough terrian, north, south, east, or west. Differing harmonic and noise conditions from one distribution line to another, or from one section of a line to another section of that line, were associated with loads operated by utility customers.

* The primary type of noise affecting the performance of DLC systems was discrete frequency harmonics of the line frequency. The sources of these harmonics were always switching devices and non-linear loads operated by utility customers. No case was identified where a utility distribution system component produced harmonics that limited the operational performance of a DLC receiver.

* Harmonic and noise amplitudes at a fixed location on a distribution line varied considerably with time and with frequency. Changes in amplitude were usually abrupt rather than gradual. Ghanges in voltage and current harmonic levels of 10 to more 30 dB were common. These changes were generally nonstationary in character, and they could not be described by conventional statistical measures of voltage or current amplitude. Whenever the sources of these changes were identified, they were associated with the switching on and off of customer loads or with the operation of a load control device.

* Experimental DLC systems from three major suppliers were observed in operation. These systems operated at frequencies from 5 to 13 kHz. All systems were limited in performance by harmonics of the power frequency that were within the bandpass of the DLC receivers.

* Resonant peaks in harmonic and noise amplitudes (voltage and current) were found at frequencies within the range useful for DLC systems on the distribution lines of all utilities. These peaks changed in amplitude and in frequency as customer loads varied by 10 to more than 30 dB.

* Signals from a DLC system operating on a distribution line were also observed on other nearby distribution lines and sometimes on distribution lines from another substation. Conducted coupling paths were responsible for the coupling of the signals onto other lines.

* Other communications systems were found that used utility distribution lines to propagate signals from one location to another location. These systems were operated by utility customers, and they employed frequencies within the range useful for utility DLC systems. While no case of direct interference was found between a DLC system and a customer operated system during this effort, any significant expansion of DLC systems by the utilities will eventually result in conflicts for operating frequencies between the utilities and their customers and in serious interference to DLC systems. The utilities should seek regulatory agency assistance to limit and control the communications signals of customers that are propagated along distribution lines.

* Gap noise was found on distribution lines at all utilities. Gap noise can be a significant source of radiated and conducted interference to many communication and radio systems that operate at frequencies from about 30 kHz to 1000 MHz. Gap noise, however, was not a source of noise or interference to DLC systems that operated at frequencies below 15 kHz.

Section 9

RECOMMENDATIONS

Recommendations for future work are summarized in the following statements. Each recommendation is discussed in more detail in Section 6 of the report.

* Utilities should develop and implement means to control and limit the growth of harmonics and noise on distribution lines that are generated by customer devices. Furthermore, harmonic levels at many locations should be reduced from present levels.

* Manufacturers and their associations should be requested to design equipment to minimize the generation of current harmonics. In addition, manufacturers of consumer equipment should design their products to be immune to harmonics.

* Standards organizations such as ANSI, NEMA, IEEE, EEI, and AEIC should be requested to modify existing standards and develop new standards to protect the utilities and their customers from other customers who have equipment that create harmonics and noise interference.

* The testing and perliminary operation of DLC systems should continue. The basic design of DLC systems appears to be satisfactory, and no technical factor was found that would inhibit the orderly implementation of large-scale systems on a nationwide basis.

* The utilities need to improve the quality, quanity, and use of instrumentation to measure harmonic and noise levels at all frequencies including frequencies useful for DLC systems. Instrumentation commonly employed by utilities for radio noise measurements is inadequate for determing interference to DLC systems.

* Investigations into DLC signal propagation losses along distribution lines and means to minimize these losses need to be continued.

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Appendix A

SUPPLEMENTAL MEASUREMENTS

SUPPLEMENTAL MEASUREMENTS

Several supplemental measurement and analysis tasks were added to the project. These supplemental efforts were in support of the primary objectives of the project or other EPRI projects. The tasks were added to the project because the instrumentation was at or near the test sites, or the instrumentation was required to accomplish the measurements.

A brief summary of each supplemental task is included in this appendix. A listing of memoranda published for the supplemental tasks is provided in Section 4.12 of the main text. Readers interested in a more complete accounting of work accomplished under these auxiliary tasks are referred to the appropiate technical memoranda. Because some of the memoranda are extensive and large, it was not feasible to include them as appendicies to this report.

Summary
of
Supplemental Task 1

SOME EFFECTS OF A RECTIFYING DEVICE ON HOUSE- AND DISTRIBUTION-LINE CURENTS

The technical characteristics of a rectifier device that was produced to prolong the life and reduce the operational cost of light bulbs was investigated. Based upon a brief examination of the operational characteristics of the device, the claim of increased life of bulbs was confirmed. The high cost of the device suggested that any operational savings would be offset by the initial cost. The device reduced the number of lumens per watt of a bulb and increased the cost of operating device-equipped bulbs for equivalent levels of lighting.

Increased current harmonic levels were produced by the device because of rectification of the alternating current, but the levels of current harmonics produced by a typical residence would not be serious. Because the rectifiers apparently were randomly polarized during their production, widespread use would not result in serious dc current levels on secondary circuits unless a utility customer with unusually heavy lighting loads tested and selected the devices for a specific polarity.

Summary
Of
Supplemental Task 2

HARMONICS AND NOISE FROM A FUEL CELL INVERTER

Measurements were made to determine the level of harmonics introduced into a distribution line by an inverter associated with a fuel-cell power source. The small physical size of the inverter, and the enclosed distribution-line configuration, made it necessary to use small electric- and magnetic-field sensors to measure harmonic voltage and current on 2-kV and 13-kV buses in the inverter cabinet. Good results were obtained for measurements on the 2-kV portion of the inverter output. An unscheduled inverter shutdown prevented obtaining desired data from the 13-kV buses. Nevertheless, a number of important findings and conclusions were reached from the data that were obtained before the inverter shutdown. These findings and conclusions include:

* Voltage harmonic levels from the inverter were nearly identical on each phase at the 2-kV level of the inverter output. A single voltage sensor is sufficient, under normal operating conditions, to establish voltage harmonic levels.

* The measured 60-Hz current and the current harmonics were lower than expected and somewhat different from phase to phase; however, this difference may have been related to the inverter adjustments. Insufficient data were obtained under standard inverter operating conditions to determine if current measurements on a single phase will be sufficient to establish normal current harmonic levels.

* The small physical size of the inverter prevented using a wideband voltage probe to measure voltage harmonics. A small electric-field sensor was installed, and it was shown to be an adequate and an accurate substitute for a directly connected, wide-band voltage probe or potential transformer.

* The small physical size of the inverter prevented making a safe installation of a wideband current probe to measure current harmonics. A small magnetic-field sensor was installed in the inverter, but the inverter shutdown prevented completing tests to fully demonstrate its ability to replace a directly-connected wideband current probe or a current transformer. Preliminary data were encouraging.

* Magnetic fields at 25 Hz and at harmonics of 25 Hz were present in the general vicinity of the inverter. These fields did not originate from the inverter.

Summary
of
Supplemental Task 3

HARMONICS AND NOISE FROM A MAGNETOHYDRODYNAMIC POWER GENERATOR INVERTER

Harmonics and noise generated by the inverter associated with the magnetohydrodynamic test facility at Butte, Montana, were measured during an extended test run of the facility. A number of specific findings and conclusions were obtained from the measurements:

* The presence of (12-pulse) magnet-power-supply harmonics (frequency domain) and their associated impulses (time domain) at higher levels than the (6-pulse) inverter harmonics and impulses complicated the analysis of measured results. Harmonic measurements alone were not sufficient to separate effects of the inverter from the effects of the magnet power supply. Complementary time-domain measurements provided data from each source of harmonics (or impulsive noise).

* Dominant voltage and current harmonics at test points within the inverter building and at the facility substation were caused by the magnetic power supply rather than from the inverter. Time-domain analysis made it possible to separate magnet-power-supply impulses fron inverter impulses, permitting a detailed analysis of each source of harmonics.

* Significant levels of voltage and current harmonics (frequency-domain) or line-synchronous impulses (time-domain) were present on the 4.16-kV side of the substation transformer. The current harmonics and related current impulses passed through the substation transformer and onto the 161-kV transmission line with little attenuation. Voltage harmonics at low frequencies were also passed through the transformer with little attenuation; however, voltage harmonics at higher frequencies and their associated voltage impulses were attenuated.

* Small electric- and magnetic-field sensors were used to obtain voltage and current harmonic data from high-voltage substation buses and from buses in the inverter building. Use of the sensors eliminated the need for directly connected voltage- and current-probes on high-voltage circuits.

Summary
Of
Supplemental Task 4

RF ATTENUATION OF A BUILDING

The isolation of the interior of an existing building from outside electromagnetic fields was investigated during a brief one-day measurement. The building was a concrete wall structure typical of that found in utility substations. Of concern was the operation and reliability of a computer system planned for the building in the presence of large external transient electromagnetic fields.

Building attenuation varied considerably with frequency. Peaks and nulls in attenuation were found as the frequency was varied. These peaks and nulls prevented establishing a single value for building attenuation.

Mean attenuation values were found useful in estimating the isolation of the building interior to broad-band electromagnetic fields. Mean values of attenuation of about 15 dB were found for impulsive signals with spectral components in the 10-to-100-MHz frequency range and about 23 dB for broad-band impulsive fields with spectral components in the 1-to-10-MHz frequency range.

Low-frequency magnetic-field measurements suggested that significant low-frequency coupling existed between external fields and the building's interior by direct conduction on the wires and cables that penetrated the building walls.

Summary
of
Supplemental Task 5

INVESTIGATION OF CAPACITOR FAILURES

Westinghouse Electric staff members had related frequent distribution line capacitor failures at two sites to ultrasonic noise in the capicators. Radio noise and distribution line harmonics were measured during a brief one-day effort to ascertain if unusual or distinctive electrical conditions were present at the sites that might be related to potential capacitor failure mechanisms.

Considerable gap noise was found from sources that were located on the distribution line support poles that also supported the capacitor banks. Additional sources of gap noise were also found on adjacent and nearby support poles. While the presence of gap noise made it difficult to measure other types of noise, gap noise was not believed to be associated with capacitor life.

The two capacitor banks under study had unusually high levels of ninth harmonics (both voltage and current harmonics). At this frequency, the capacitor impedance was sufficiently low that significant current was flowing through the capacitors. Also, the capacitors were subjected to intermittent high-current bursts originating from a nearby industrial facility. The spectral energy of the current bursts was centered at about 10 kHz.

Summary
of
Supplemental Task 6

ELECTRICAL ENVIRONMENT OF HOMES

An examination of harmonics and noise on the wiring of homes and of electromagnetic fields in and around homes was undertaken on residences located in the San Francisco Bay area. Conducted voltage and current were examined with probes directly connected to the house wiring. Electromagnetic fields were investigated with electric- and magnetic- field sensors.

The spectral and temporal features of radio noise generated by household appliances such as television sets, home computers, vacuum cleaners, mixers, blenders, light dimmers, induction motors, and other devices were defined.

The electromagnetic fields outside, around, and inside homes were measured. These measurements defined the amplitude of electric and magnetic fields at the 60-Hz fundamental frequency of the electric power and at harmonics of the fundamental. Spatial variations of the fields were investigated. The affect of fields from nearby distribution lines and from a substation adjacent to a home on ambient fields inside homes was examined.

Summary
Of
Supplementary Task 7

TRANSMISSION-LINE FAULTS

Intermittent transmission line faults in remote regions are often difficult to locate. An investigation of the possibility of employing direct electromagnetic radiation from the fault arc or from impulse current from the fault was conducted at a remote desert site. Four faults on a 235-kV transmission line (two line to ground, one line to line, and one line to shield wire) were staged by the utility operating the line. Electromagnetic fields associated with the faults were measured at three sites.

All faults were successfully implemented. Voltage and current transients from the fault were defined by a site located along the line four miles from the fault. The 60-Hz fundamental voltage and current harmonics were measured and defined before the fault, during the fault, and after the fault. Plots of voltage and current during the fault were obtained for the fundamental and its primary harmonics.

Harmonic currents were low (less than 10 percent) before the fault, but they increased to nearly the value of the fundamental current (70 to 90 percent) during the faults. The fundamental line current increased by a factor of about 3 to 5 during the faults.

Electromagnetic fields radially from the line at frequencies below 1 MHz were very weak at a distance of four miles. The field strength was insufficient for fault location purposes.

Summary
Of
Supplemental Task 8

HARMONICS AND NOISE FROM ELECTRIC AUTOMOBILE BATTERY CHARGERS

Ten electric automobiles were assembled at a suburban location. The automobile batteries were charged during the evening hours when electric rates were favorable. Charging tests were conducted with all ten chargers operating, with five chargers operating, and with a single charger operating.

The secondary providing power to the chargers was instrumented with wideband current and voltage probes. The distribution line providing power to the chargers and residences in the area was instrumented with wide-band electric- and magnetic-field sensors. The instrumentation was operated when the automobiles were not charging to observe ambient conditions, at times of maximum charge rate, at times of medium charge rates, and at minimum charge rates.

Voltage and current harmonics on the secondary were determined during the various charging conditions. The spectral and temporal properties of radio noise from the charger control circuits was defined.

Summary
of
Supplemental Task 9

HARMONICS AND NOISE FROM THE BEST CONVERTER

The Battery Energy Test Facility (BEST) is a facility to investigate a method of storing electrical energy for use during times of peak loads. Harmonics and noise introduced into a 13-kV distribution line by the inverter were measured under various battery charging and discharging rates.

The primary and most significant finding of the measurements was that the BEST facility did not degrade the quality of electrical power on the interconnected distribution lines. Harmonic levels and impulsive noise levels from the facility inverter were below ambient line levels one mile from the facility.

Additional conclusions and findings of the BEST measurements are as follows:

* The dominant features of the voltage and current harmonics generated by the BEST facility inverter was the distinctive pairs of characteristic harmonics. The amplitude of the harmonic pairs exceeded the amplitude of all other harmonics and noise produced by the inverter, and they were in accord with the proper functioning of a 24-pulse inverter.

* The inverter output filter capacitors, when they were switched into the circuit, reduced both voltage and current harmonics on the distribution lines feeding the facility to near ambient levels.

* The amplitude of the characteristic harmonics versus frequency has an approximate 1/m variation at the converter 4.16-kV output. The amplitude behavior of the characteristic harmonics on the 13.8-kV output level was strongly influenced by the components outside of the BEST inverter building. For example, the 4.16/13.8 kV transformer performed as a low-pass filter. Characteristic harmonics at low frequencies passed through the transformer with littleattenuation, but frequencies above about 7 kHz were attenuated by the transformer.

* The directly connected voltage probe and magnetic-field sensor installed close to the Phase A bus of the 13.8 kV output provided excellent and accurate results. The electric- and magnetic-field sensors installed under the distribution line reproduced the general temporal and spectral propertied of the harmonics, but they did not provide absolute magnitudes of the harmonics because of the phase effects of the fields surrounding the three-phase distributiuon lines.

* Charging and discharging of the BEST batteries yeilded similar voltage and current harmonic amplitudes.

* Series and parallel battery configurations gave only minor differences in voltage and current harmonic amplitudes.

* Changes in battery charge or discharge rates produced complex nonlinear changes in the amplitudes of voltage and current harmonics below about 7 kHz. Above this frequency, changes in harmonics were minimal.

Appendix B

MEASUREMENT PARAMETERS

MEASUREMENT PARAMETERS

Measurement system details and instrumentation operating parameters are required to scale and analyze data contained in figures in this report. To aid those interested in additional analysis of data, system operating parameters and other data necessary to interpert the figures are presented in a small table for each figure that contains data. These tables are made as concise as possible to simplify the presentation of the needed data.

The appendix provides (1) the identification of terms and parameters used to describe instrument settings and other items, (2) a list of abreviations used in the table of parameters for each figure, and (3) the tables of parameters for each figure. The instrumemtation configuration employed to obtain data is identified in each figure by a letter following the date of the measurement.

1. IDENTIFICATION OF PARAMETERS IN TABLES

For measurements made with Configuration A, the Hewlett Packard 140/141 Series Spectrum Analyzer and the Develco Model 7200B 3-Axis Display, the parameters are:

Line 1--Local time of day, date of measurement, system identification

Line 2--Organization, substation, distribution-line No., site, additional site detail if needed

Line 3--Measurement, sensor type, line-amplifier gain, analyzer input attenuation, analyzer IF gain

Line 4--Center frequency, frequency scan width, IF bandwidth, scan time

For measurements made with Configuration B, the Nicolet Model UA500A Spectrum Analyzer and the Develco Model 7200B 3-Axis Display, the parameters are:

Line 1--Local time of day, date of measurement, system identification

Line 2--Organization, substation, distribution-line No., site, additional site detail if needed

Line 3--Measurement, sensor type, line amplifier gain, analyzer input attenuation, analyzer output gain

Line 4--Start frequency, stop frequency, terminate frequency, time-axis expansion factor

For measurements made with Configuration C, the Hewlett-Packard Model 3582A Spectrum Analyzer, the parameters are:

Line 1--Local time of day, date of measurement, system identification

Line 2--Organization, substation, distribution-line No., site, additional site detail if necessary

Line 3--Measurement, sensor type, line amplifier gain

For measurements with Configuration D, an oscilloscope, the parameters are:

Line 1--Local time of day, date of measurement, system identification

Line 2--Organization, substation, distribution-line No., site, additional site detail if necessary

Line 3--Measurement, sensor type, line amplifier gain, oscilloscope gain, oscilloscope sweep speed

Note: A line is sometimes added at the bottom of a table to provide additional information about a measurement. This line may contain additional abreviations that are found in the IEEE Dictionery Of Terms and Abreviations.

Occasionally, measurement parameters do not fit the rigid structure of the formats listed above. In such cases, the data are entered in logical locations. For example, a street address may be substituted for a distribution line number when the street address is more appropiate.

2. ABREVIATIONS USED IN TABLES

A number of abreviations are used in the tables of parameters for each figure. Whenever possible standard abreviations familiar to utility personnel are employed. These abreviations are:

PG&E	Pacific Gas & Electeric Company
SDG&E	San Diego Gas & Electric
APS	Ariziona Public Service Company
TES	Texas Electric Service Company
PSE&G	Public Service Electric & Gas Company
SCP	South Central Power Company
DE	Detroit Edison
FP&L	Florida Power & Light Company
CP&L	Carolina Power & Light Company
VEPCO	Virginia Electric Power Company
NP	Nevada Power Company
Sub	Substation Location
LA	Los Angeles
WJ8888	Watkins-Johnson Model 8888 Receiver
SW	Switch
V	Voltage Measurement
I	Current measurement
E	Electric-field measurement
B	Magnetic-intensity measurement
E100A	Electric-field sensor, Model No. E100A
B100	Magnetic-field sensor, Model No. B100
B101	Magnetic-field sensor, Model No. B101
P201D	Voltage probe, Model No. P201D
CT5	Current probe, Model No. CT5
1M	1-meter rod
3M	3-meter rod

3. TABLES OF MEASUREMENT PARAMETERS

Figure 5-2

1205, 11-4-82, B
NP, XXXX, Hodges, Instrumentation Bldg
E, 1M, +60, 0, +20
0, 0.2, T0.2, *4

Figure 5-3

1332, 12-5-84, B
OP, XXXX, 13.8 kV,
E, E100A, +40, -20, +10
0, 1 kHz, T0.3 kHz, *5

Figure 5.4

XXXX, XX-XX-XX, C
PG&E, 138 kV, Pacheco Pass
B, B101, XX

Figure 5-5

1133, 1133A, 9-28-84, C
CP&L, Cary, Sub, PCC
V, P201D(-20), 0

Figure 5-6

1018, 9-28-84, B
CP&L, Cary, Sub, PCC
V, P201D(-20), 0, -20, +10
0, 20 kHz, T20 kHz, *2

Figure 5-7

1337, 9-28-84, C
CP&L, Cary, Sub, PCC
V, P201D(-20), 0

Figure 5-8

0922, 10-8-84, B
CP&L, Cary, Sub, 115 V
V, P201-D, +20, -10, +10
0, 2 kHz, T2 kHz, *1

Figure 5-9

0920, 10-8-84, B
CP&L, Cary, Sub, 115 V
V, P201-D(-20), +20, -10, +10
0, 20 kHz, T20 kHz, *1

Figure 5-10

1021, 10-8-84, B
CP&L, Piney Plains, Sub, 115 V
V, P201D(-20), +20, -10, +10
0, 2 kHz, T2 kHz, *1

Figure 5-11

1018, 10-8-84, B
CP&L, Piney Plains, Sub, 115 V
V, P201D(-20), +20, -10, +10
0, 20 kHz, T20 kHz, *1

Figure 5-12

1246, 10-8-84, C
CP&L, Raleigh South, 115 V
V, P201D(-20), +20

Figure 5-13

1310, 10-8-84, B
CP&L, Raleigh South, Sub, 115 V
V, P201D(-20), +20, -5, +10
0, 10 kHz, T10 kHz, *4

Figure 5-14

1222, 10-8-84, A
CP&L, Raleigh South, Sub, 115 V
V, P201D(-20), +20, -10, 0
V, P201D(-20), +20, -10, 0
250 kHz, 500 kHz, 3 kHz, 200 ms

Figure 5-15

1108, 10-11-84, B
CP&L, Apex, DC160, PCC
V, P201D(-20), +20, -20, +10
0, 20 kHz, T20 kHz, *1

Figure 5-16

1141, 10-11-84, B
CP&L, Apex, DC160, PCC
V, P201D(-20), +20, -20, +10
0, 20 kHz, T20 kHz, *2

Figure 5-17

1525, 4-12-83, B
PG&E, XXXX, 13.8 kV Secondary, Kriste Ln, Induction Motor
I, CT5, 20/1, 10/1
0, 0.2 kHz, T0.2 kHz, *3

Figure 5-18

2034, 4-25-83, B
PG&E, XXXX, 13.8 kV Secondary, Kriste Ln, Shop Vac
I, CT5, 20/1, 10/1, +20, -10, +10
0, 10 kHz, T10 kHz, *1

Figure 5-19

XXXX, XX-XX-XX, B
APS, XXXX, 5th St
E, 1M, 0, 0, -30

Figure 5-20

1354, 11-7-81, A
PG&E, XXXX, Morgan Hill, Hale-Live Oak, 13.8 kV
E, 3M, 0, 0, -20
50 MHz, 0 MHz, 30 kHz, 20 ms

Figure 5-21

1400, 3-5-84, A
FP&L, XXXX, Keys Rd, 13.8 kV
55 MHz, 0, 30 kHz, 20 ms
E, 1M, +24, 0, -30

Figure 5-22

1511A, 11-26-84, A
VEPCO, XXXX, 327, 34.5kV, BM82
150 MHz, 0, 100 kHz, 20 ms
E, 1M, +24, 0, -20

Figure 5-23

1550, XX, XX, XX, A
APS, XXXX, 13.8kV, 5th ST
50 MHz, 100 MHz, 30 kHz, 100 ms
E, 1M, 0, 0, -30

Figure 5-24,

1403, 12-6-79, A
PG&E, XXXX, 13.8 kV, Morgan Hill
53 MHz, 0, 10 kHz, 100 ms
E, 1M, 0, 0, -20

Figure 5-25

XXXX, XX-XX-XX, A
APS, XXXX, 13th-Virginia, 13.8 kV
E, 3M, 0, 0, -40
150 MHz, 100 MHz, 10 kHz, 200 ms

Figure 5-26

1413, 11-7-81, A
PG&E, XXXX, Morgan Hill, Hale-Kalana, 13.8 kV
E, 1M, 0, 0, -20
100 MHz, 200 MHz, 100 kHz, 200 ms
Moving At 25 MPH

Figure 5-27

1049, 11-30-84, A
VEPCO, XXXX, 327, NI69
E 1M, +24, 0, -20
120 Mhz, 100 MHz, 100 kHz, 200 ms

Figure 5-28

1054, 11-30-84, A
VEPCO, XXXX, 327, NI69
E, 1M, +24, 0, -20
120 MHz, 100 MHz, 100kHz, 200 ms

Figure 5-29

1057, 11-30-84, A
VEPCO, XXXX, 327, NI69
E, 1M, +24, 0, -20
150 MHz, 200 MHz, 100 kHz, 200 ms

Figure 5-30

1545, 3-5-84, A
PG&E, XXXX, 13.8 kV, Hwy 12/116, Al Boat Mfg
E, 1M, 0, 0, -40
50 MHz, 0, 100 kHz, 50 ms

Figure 5-31

1120, 12-22-83, A
PG&E, XXXX, 13.8 kV, Hwy 12/116, Al Boat Mfg
E, 1M, 0, 0, -20
25 MHz, 50 MHZ, 300 kHz, 100 ms

Figure 5-32

1444, 2-12-82, C
SDG&E, El Cajon, Sub, S. Bus, Y, B-N
I, CT5, 20/1, 10/1, 0

Figure 5-33

1444A, 2-12-82, C
SDG&E, El Cajon, Sub, S. Bus, Y, B-N
I, CT5, 20/1, 10/1, 0

Figure 5-34

1151, 2-12-82, C
SDG&E, El Cajon, 6255 Fernwood, 115 V
V, P201D(-20), 0
CAP BANK GA2-92CF Open

Figure 5-35

1038, 2-11-82, C
SDG&E, El Cajon, 6255 Fernwood, 115 V
V, P201D(-20), 0

Figure 5-36

1103, 2-8-82, C
SDG&E, Murray, 8448 Jackie, 115 V
V, P201D(-20), 0
I, CT5, 20/1, 10/1, 0

Figure 5-37

0920, 2-11-82, C
SDG&E, El Cajon, 1181 Rathmoor, 115 V
V, P201D(-20), 0

Figure 5-38

1446, 2-10-82, C
SDG&E, El Cajon, 1101 S. Mollison, 115 V
V, P201D(-20), 0

Figure 5-39

0955, 2-12-82, C
SDG&E, El Cajon, Westwind/Essex, 115 V
I, CT5, 20/1, 10/1, +40

Figure 5-40

1330, 11-32-81, B
PG&E, XXXX, Vineyard/Isabel, 13.8 kV
E, 1M, +30, 0, +10
0, 10 kHz, T10 kHz, *4

Figure 5-41

1335, 11-23-81, B
PG&E, XXXX, Vineyard/Isabel, 13.8 kV
B, B101, +30, 0, +10
0, 10 kHz, T10 kHz, *5

Figure 5-42

1359, 11-23-81, B
PG&E, XXXX, Vineyard/Isabel, 13.8 kV
B, B101, +30, 0, +10
0, 10 kHz, T10 kHz, *5

Figure 5-43

1421, 11-23-81, B
PG&E, XXXX, Vineyard/Isabel, 13.8 kV
B, B101, +30, 0, +20
0, 10 kHz, T10 kHz, *5

Figure 5-44

1500, 11-23-81, B
PG&E, XXXX, Vineuard/Isabel
B, B101, +30, 0, +20
0, 10kHz, T10 kHz, *5

Figure 5-45

1355, 2-15-82, B
LA, XXXX, Altran
E, 1M, WJ8888, 0, 0, 0
0, 0.5 kHz, T0.5 kHz, *2

Figure 5-46

1344, 2-15-82, B
LA, XXXX, Altran
E, 1M, WJ8888, 0, 0, 0
0, 0.5 kHz, T0.5 kHz, *2

Figure 5-47

1044, 11-29-84, A
VEPCO, Hopewell, Sub, SW V34
E, 1M, +24, 0, -20
100 MHz, 100 MHz, 100 kHz, 200 ms

Figure 5-48

1039, 11-29-84, A
VEPCO, Hopewell, Sub, SW V34
E, 1M, +24, 0, -20
80 MHz, 20 MHz, 100 kHz, 200 ms

Figure 5-49

1103, 11-29-84, A
VEPCO, Hopewell, Sub, SW V34
E, 1M, 0, -20
50 MHz, 100 MHz, 100 kHz, 200 ms

Figure 5-50

1027, 11-29-84, A
VEPCO, Hopewell, Sub, SW V34
E, 1M, +24, 0, -20
75 MHz, 0, 100 kHz, 50 ms

Figure 5-51

1032, 11-29-84, A
VEPCO, Hopewell, Sub, SW V34
E1M, +24, 0, -20
75 MHz, 0, 100 kHz, 20 ms

Figure 6-1

1132, 9-27-84, A
CP&L, Apex, Sub, PCC
V, P201D(-20), 0, -30, +10
50 kHz, 100 kHz, 3 kHz, 100 ms